Bilinear $\not{R}_p$ SUSY:

Solar and atmospheric ν problems

Martin Hirsch

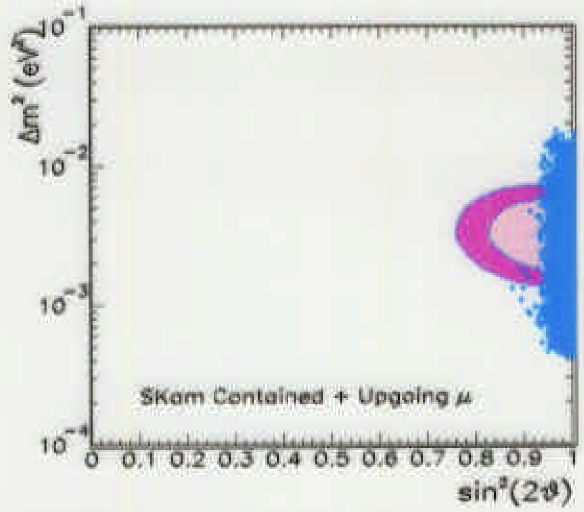
IFIC/CSIC
Universitat de València

1. Motivation: Current neutrino problems
2. Bilinear $\not{R}_p$ SUSY at 1-loop
3. Numerical results
4. Summary

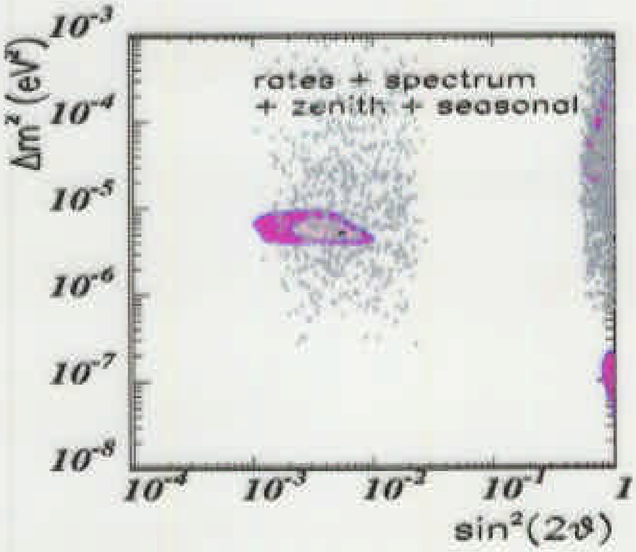
Based on: M. Hirsch, M.A. Diaz, W. Porod, J.C. Romão and J.W.F. Valle, hep-ph/0004115, Phys.Rev. D, in press

Solar and atmospheric ν problems:

Fits versus bilinear $\not{R}_p$ MSSM at 1-loop



M.C. Gonzalez -Garcia et al., hep-ph/9906469



M.C. Gonzalez -Garcia et al., hep-ph/9910494

Bilinear R-parity breaking

extension of the MSSM

Take the Minimal Supersymmetric extension of the Standard Model (MSSM), add to the superpotential:

$$W = W_{MSSM} + \epsilon_i \hat{L}_i \hat{H}_u$$

and to the soft supersymmetry breaking terms:

$$V^{soft} = V_{MSSM}^{soft} + B_i \epsilon_i \tilde{L}_i H_u$$

⇒ Note that unless $B_{MSSM} \equiv B_i \; and \, m_{H_d}^2 \equiv m_{L_i}^2$ the bilinear terms can not be eliminated simultaneously from $V^{soft} \; and \, W$.

⇒ $\epsilon_i \hat{L}_i \hat{H}_u$ and $B_i \epsilon_i \tilde{L}_i H_u$ violate lepton number

⇒ Presence of $B_i \epsilon_i \tilde{L}_i H_u$ implies that tadpole equations for sneutrinos are non-trivial: Sneutrino fields acquire VEV

⇒ Only 3 new parameters

Tree-level neutralino mass matrix

As a consequence of $R\!\!\!/_p$ neutrinos and neutralinos mix.

In the basis:

$$\Psi_0'^T = (\nu_e, \nu_\mu, \nu_\tau, -i\lambda', -i\lambda_3, \psi_{H_1}^1, \psi_{H_2}^2)$$

The neutralino mass matrix can be written in a block form,

$$\mathcal{M}_0 = \begin{pmatrix} 0 & m \\ m^T & \mathcal{M}_{\chi^0} \end{pmatrix}.$$

where:

$$m = \begin{pmatrix} -\frac{1}{2}g'\langle\tilde{\nu}_e\rangle & \frac{1}{2}g\langle\tilde{\nu}_e\rangle & 0 & \epsilon_e \\ -\frac{1}{2}g'\langle\tilde{\nu}_\mu\rangle & \frac{1}{2}g\langle\tilde{\nu}_\mu\rangle & 0 & \epsilon_\mu \\ -\frac{1}{2}g'\langle\tilde{\nu}_\tau\rangle & \frac{1}{2}g\langle\tilde{\nu}_\tau\rangle & 0 & \epsilon_\tau \end{pmatrix},$$

$\mathcal{M}_{\chi^0}$ is the MSSM neutralino mass matrix, given by,

$$\mathcal{M}_{\chi^0} = \begin{pmatrix} M_1 & 0 & -\frac{1}{2}g'v_d & \frac{1}{2}g'v_u \\ 0 & M_2 & \frac{1}{2}gv_d & -\frac{1}{2}gv_u \\ -\frac{1}{2}g'v_d & \frac{1}{2}gv_d & 0 & -\mu \\ \frac{1}{2}g'v_u & -\frac{1}{2}gv_u & -\mu & 0 \end{pmatrix}.$$

$\Rightarrow$ $\mathcal{M}_0$ has texture such that at tree-level only one neutrino picks up mass

Approximation formula for neutrino mass at tree-level

If the $R\!\!\!/_p$ parameters are small in the sense that for

$$\xi = m \cdot \mathcal{M}_{\chi^0}^{-1}$$

all $\xi_{ij} \ll 1$, then matrix Ξ, which diagonalizes the neutralino mass matrix can be approximated by:

$$\Xi^* = \begin{pmatrix} V_\nu^T & 0 \\ 0 & N^* \end{pmatrix} \begin{pmatrix} 1 - \frac{1}{2}\xi\xi^\dagger & -\xi \\ \xi^\dagger & 1 - \frac{1}{2}\xi^\dagger\xi \end{pmatrix}$$

Second matrix above block-diagonalizes $\mathcal{M}_0$ approximately to the form diag$(m_{eff}, \mathcal{M}_{\chi^0})$, where

$$m_{eff} = \frac{M_1 g^2 + M_2 g'^2}{4det(\mathcal{M}_{\chi^0})} \begin{pmatrix} \Lambda_e^2 & \Lambda_e\Lambda_\mu & \Lambda_e\Lambda_\tau \\ \Lambda_e\Lambda_\mu & \Lambda_\mu^2 & \Lambda_\mu\Lambda_\tau \\ \Lambda_e\Lambda_\tau & \Lambda_\mu\Lambda_\tau & \Lambda_\tau^2 \end{pmatrix}$$

with,

$$\Lambda_i = \mu\langle\tilde{\nu}_i\rangle + v_d\epsilon_i.$$

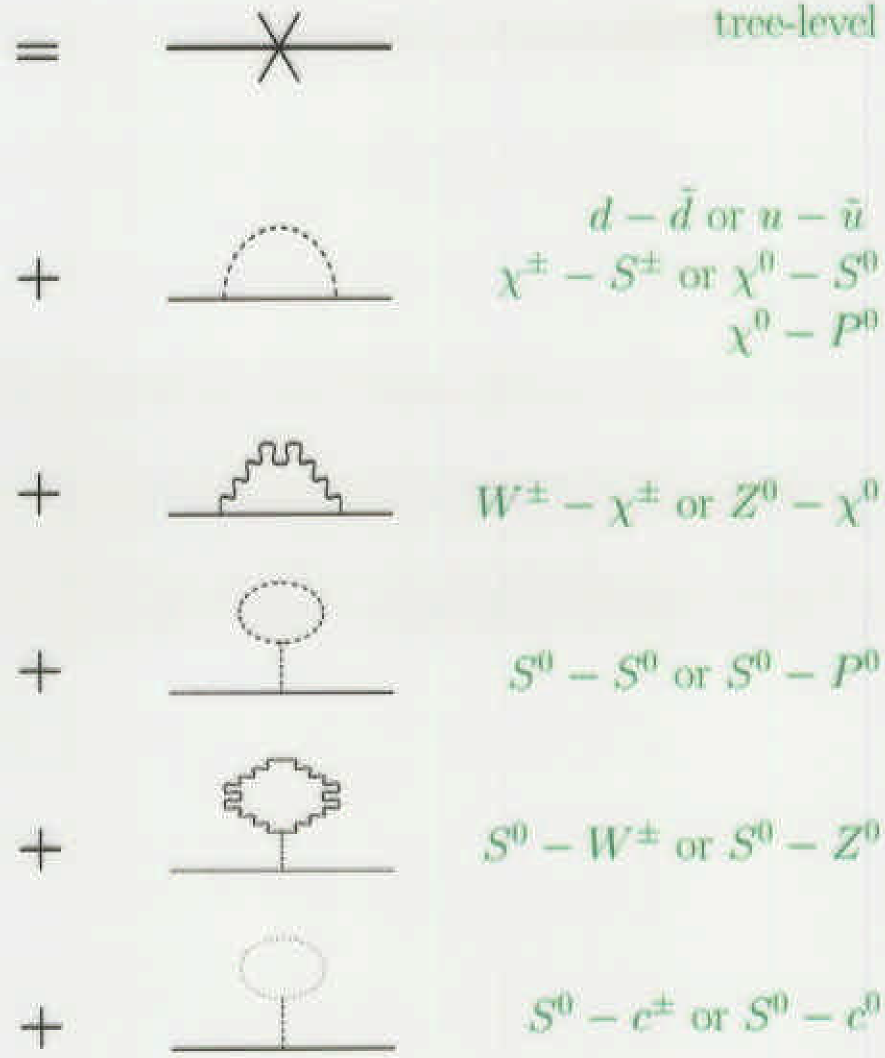
The only non-zero neutrino mass is then given by

$$m_\nu = Tr(m_{eff}) = \frac{M_1 g^2 + M_2 g'^2}{4det(\mathcal{M}_{\chi^0})} |\vec{\Lambda}|^2.$$

1-loop corrected neutrino/neutralino mass matrix

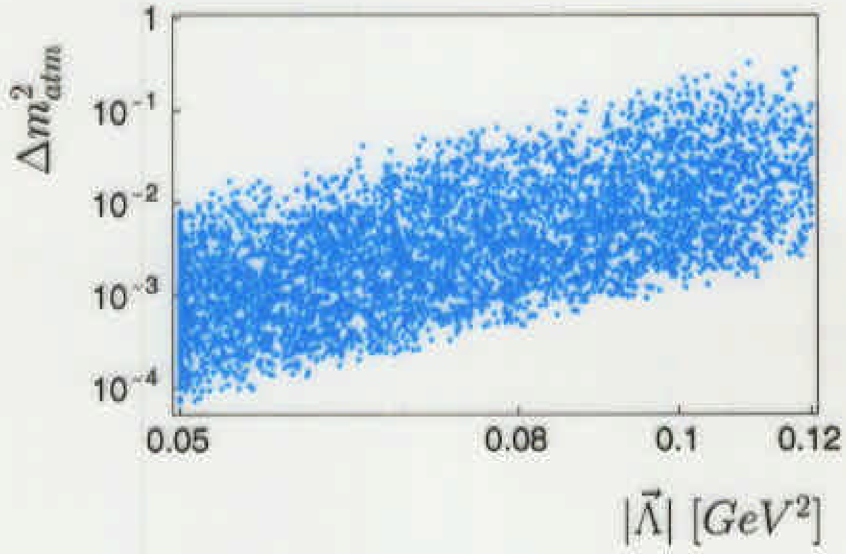
The one–loop corrected mass matrix is given by

$$M^{1L} = M^{0L}_{diag} + \Delta M^{1L}$$

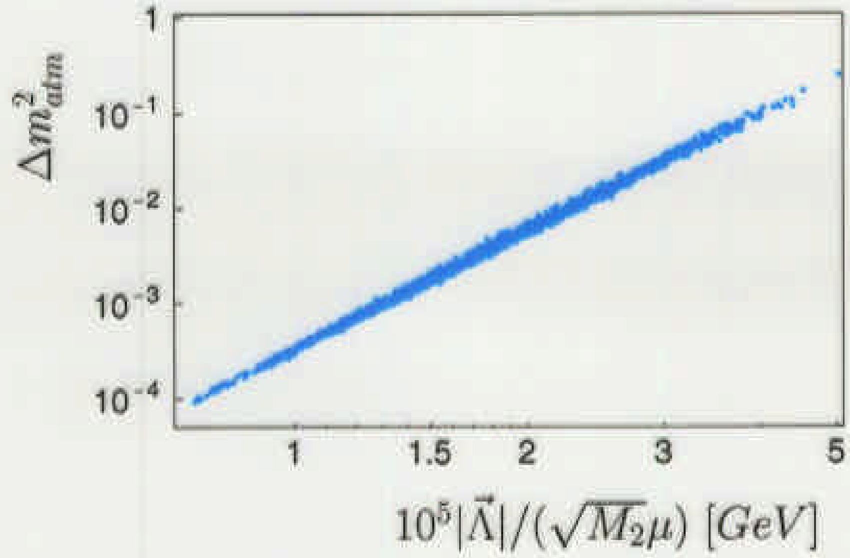


⇒ Complete set necessary for gauge independence!

Δm^2_{atm} and the alignment vector



Range of $|\vec{\Lambda}|$, giving the correct Δm^2_{32} to solve the atmospheric neutrino problem



Using the tree-level estimation to fix $|\vec{\Lambda}|$ as a function of μ and M_2.

The atmospheric angle

If $m_\nu^{loop} \leq m_\nu^{tree}$, the composition of the 3rd mass eigenstate is approximately given by:

$$U_{e,3} = \sin[Atan(\frac{\Lambda_e}{\sqrt{\Lambda_\mu^2 + \Lambda_\tau^2}})]$$
$$U_{\mu,3} = \sin[Atan(\frac{\Lambda_\mu}{\sqrt{\Lambda_e^2 + \Lambda_\tau^2}})]$$
$$U_{\tau,3} = \sin[Atan(\frac{\Lambda_\tau}{\sqrt{\Lambda_\mu^2 + \Lambda_e^2}})]$$

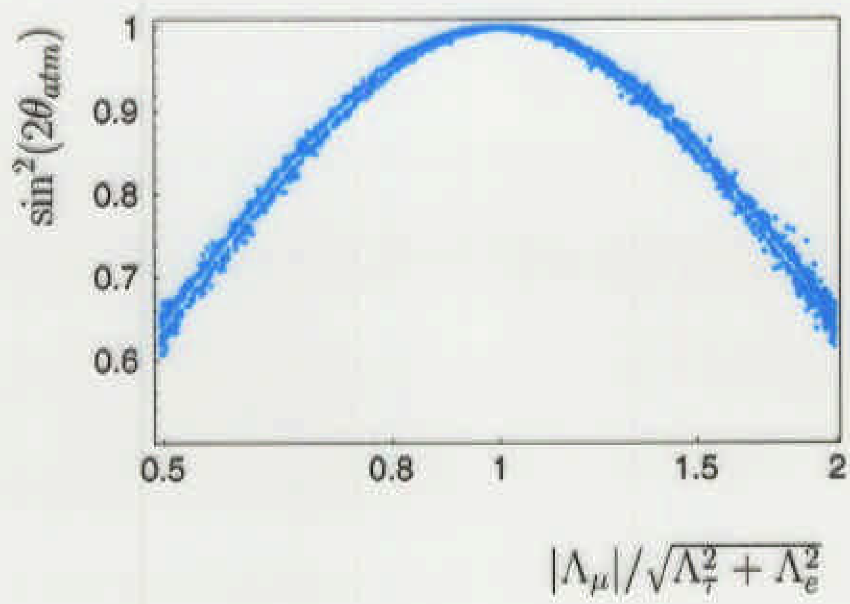
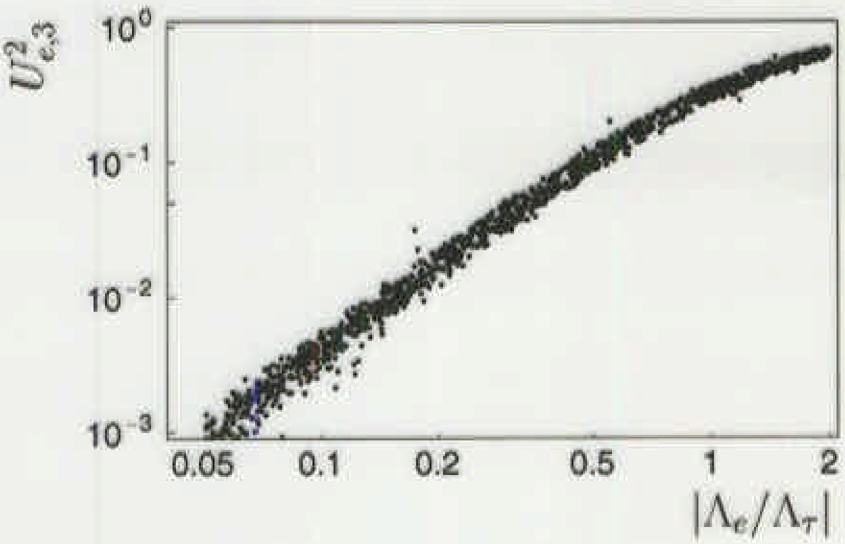


Figure: *The atmospheric angle as a function of* $|\Lambda_\mu|/\sqrt{\Lambda_\tau^2 + \Lambda_e^2}|$.

Atmospheric neutrinos and CHOOZ



CHOOZ and Super-K results prefer oscillations between

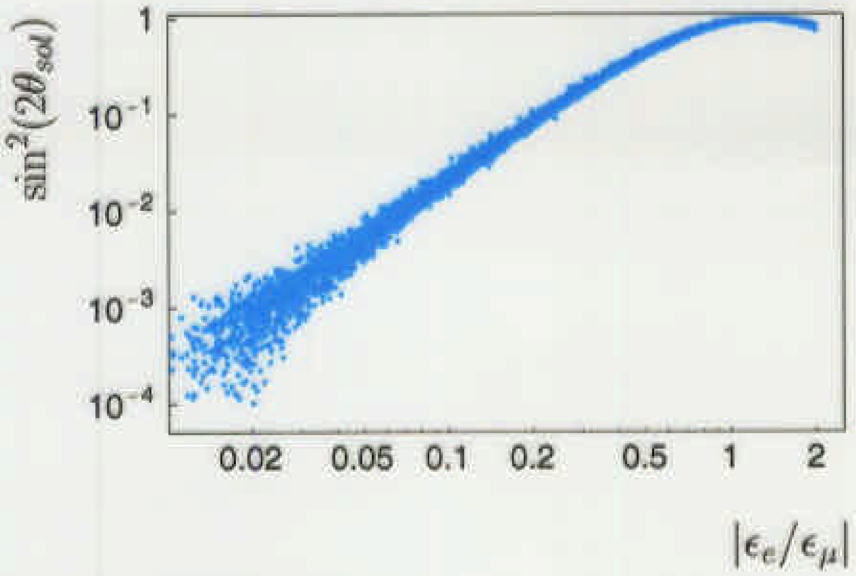
$$\nu_\mu - \nu_\tau$$

If $\Delta m^2_{atm} \geq 2 \times 10^{-3}\ eV^2$, CHOOZ actually gives limit:

$$U^2_{e,3} \leq 0.05$$

$\Rightarrow$ Thus, $\Lambda_e \leq (0.3 - 0.4)\Lambda_\mu \simeq \Lambda_\tau$. Exact equality of Λ_i's not allowed

The solar angle



⇒ GUT scenario: $\epsilon_i/\epsilon_j \sim \Lambda_i/\Lambda_j$

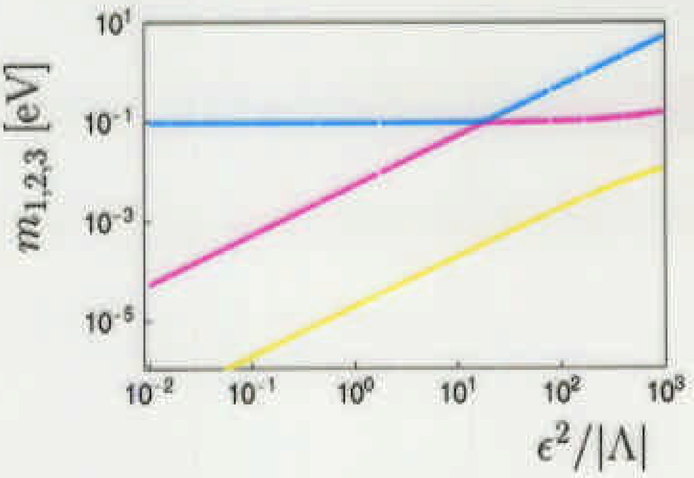
⇒ Only SA-MSW allowed

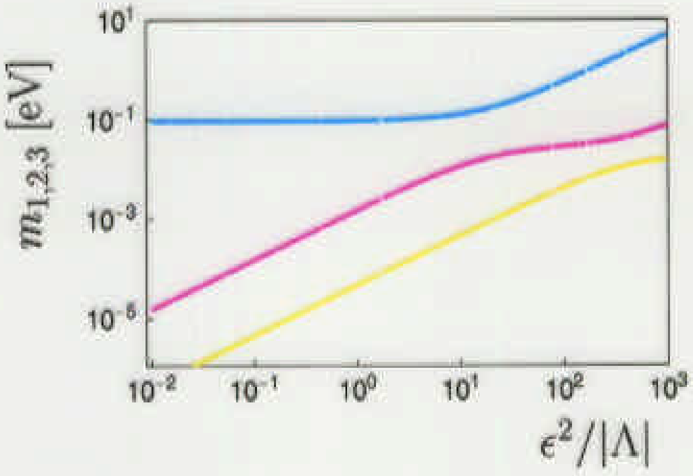
⇒ Non-GUT scenario:

⇒ If $|\epsilon_1/\epsilon_2| \simeq 1$, the solar angle $\sin^2(2\theta_{sol}) \to 1$

MSW or vacuum oscillations?

Just two examples of the neutrino spectrum as function of $\epsilon^2/|\Lambda|$:

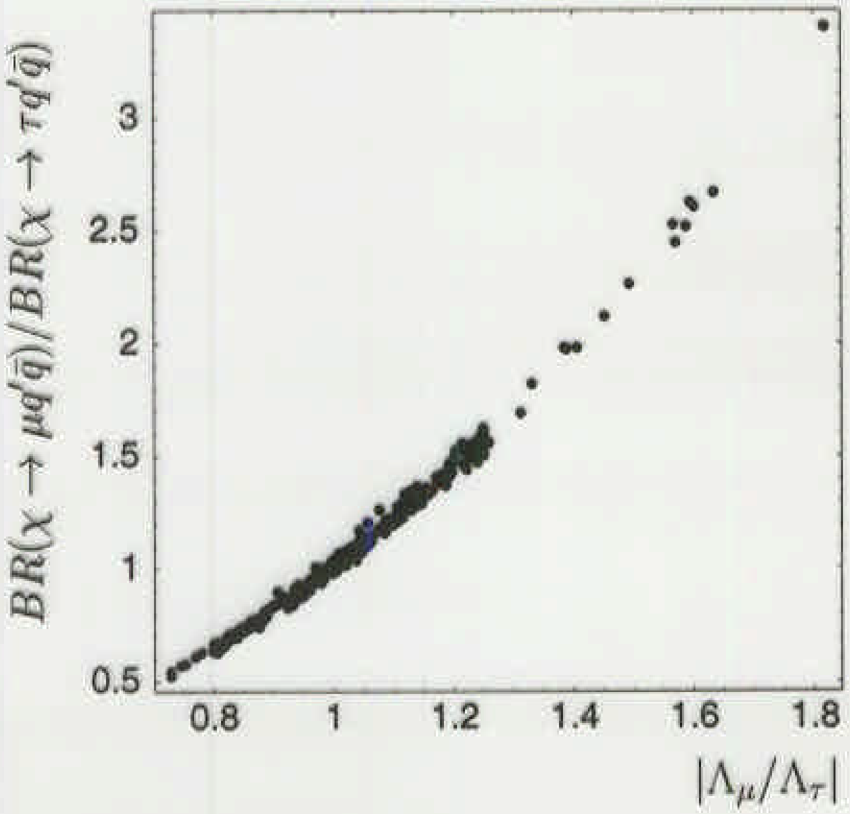




⇒ Note: Large $\tan\beta$ increases loops strongly

Semileptonic Neutralino decay

branching ratios



J.W.F. Valle et al., parallel session PA11G and: W. Porod et al. in preparation

Ratio of branching ratios for semileptonic LSP decays into muons and taus: $BR(\chi \to \mu q'\bar{q})/BR(\chi \to \tau q'\bar{q})$ as function of Λ_μ/Λ_τ.

Directly correlated with atmospheric angle!

Summary

⇒ Bilinear $R\!\!\!/_p$ SUSY is a very simple extension of the MSSM

⇒ Can solve solar and atmospheric neutrino problems if 1-loop contributions are taken carefully into account

⇒ Big advantage: Testable within a few years at accelerators